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# 10 Ghz Optical Modulator using CPS structure for communication and Sensing

P.Daud<sup>1\*</sup>, D.P. Kurniadi<sup>1</sup>, D. Mahmudin<sup>1</sup>, Y.N. Wijayanto<sup>1</sup>, P.Putranto<sup>1</sup>,  
E.J.Pristianto<sup>1</sup>, A.Nurrahman<sup>1</sup>, Andriana<sup>2</sup>, Zulkarnaen<sup>2</sup>, O.Vertus<sup>2</sup>

<sup>1</sup>Research Center for Electronics and Telecommunication (PPET), Indonesian Institute of Sciences (LIPI), Bandung, Indonesia

<sup>2</sup>Faculty of Electro, Universitas Langlangbuana, Bandung, Indonesia

\*Corresponding author: pamungkasdaud@lipi.go.id

**Abstract.** The combination of wireless millimeter-wave (MMW) bands and fiber optic cables is able to compensate the propagation loss of millimeter waves in broadband communications and high-resolution imaging. This paper discusses the design and the realization of optical modulator using coplanar stripline (CPS) structure completed with the u-slot antenna patch for RF signal input. The substrate used for CPS structure is Lithium Niobat (LiNbO<sub>3</sub>) due to its large electro optical coefficient. A 10 GHz radio wave frequency is inputted via microstrip u-slot antenna patch array 2 x 1 with input impedance 50 Ω, and acceptable return loss -10 dB. The light waves for the carrier are generated from the laser diode. Several measurements have been completely done and reported. The design is carried out by means of varying physical variable value which results in specification of the operating frequency 10 GHz. This is a pure research since the obtained results are not directly applied to the radio-over-fiber (RoF) technology.

**Keywords:** Coplanar Stripline(CPS), Radio over Fiber, Radio Wave (RF), light wave, optical modulator

## 1. Introduction

Wireless telecommunication system is increasingly growing [1]. This made radio frequency (RF) band is getting crowded so that the frequency usage is increasingly shifting to millimeter wave (MMW) / 30 GHz - 300 GHz wavelength and light waves (LW). One of the applications of RF-LW interaction which is important in the telecommunications system is a device or circuit module called converter or better known as optical modulator. This converter has several advantages such as having low induction effect and low power consumption. This device usually be applied in telecommunication systems with wide bandwidth and in electromagnetic field measurement systems with low induction effects.

The use of a millimeter-wave (MMW) band optical modulator for wireless telecommunications systems combined with fiber optic cables can also compensate the propagation loss of high-frequency band (millimeters-wave band) which is used for broadband communications and high resolution imaging. MMW wireless technology is promising for fifth generation (5G) mobile communication systems due to its outstanding characteristics for broadband data transfer and massive connection capability. MMW is also important for high-resolution radar, remote sensing, and imaging systems.



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Therefore, studies on MMW components, devices, and sub-systems have recently been attracting a lot of researchers. However, MMW is not suitable for long distance (>10 km) free-space transmission since it has a large propagation loss in air [2]. Radio-over-fiber (RoF) technology is a solution to connect many cells over a small coverage area by the use of extremely low-loss silica fibers (~0.2 dB/km at  $\lambda = 1550$  nm) in wireless MMW communication systems [3]. Moreover, RoF technology is useful for radar and sensing application systems. In MMW RoF systems, a signal conversion device from MMW to LW is significant. We have proposed several devices for converting MMW signals to LW signals using planar antennas and electro-optic (EO) crystals [4,5]. Although MMW has positive advantages for communication system, microwave (MW) is still better for long distance because of its small propagation loss.

In this paper, a new EO integrated modulator using 4 coplanar stripline array structure is proposed. With array structure, the gain of the electric field induced across the narrow gap for optical modulation are all increased. Therefore, the conversion efficiency from RF to LW is expected to be improved.

## 2. Theorem

### 2.1. Coplanar Stripline

There are several kind of exploitable structures to make an optical modulator. One among them is resonator electrode structure [6]. The main idea of this structure is that once the light wave enter the structure at passband frequency of the resonator, the electro-optic effect occurred and resulted in changes of refraction index. In the design, the utilized resonator electrode structure is Coplanar Stripline (CPS). CPS consists of substrate with 2 conductor plates arranged parallel and separated by a tiny space. The advantages of CPS are the ability to be put in series or shunt and that it is a balance transmission channel [3,7].

The characteristics of CPS are small losses, little distortion, insensitive to substrate thickness, and easy to build in either open-ended or short-ended [7,8]. To obtain the width of the conductor plate and the distance between both conductors, the equation below is given. To calculate the distance between conductor plates ( $W$ ) is expressed as following equations, when the width of conductor plate ( $S$ ).

$$\frac{W}{h} \leq \frac{10}{1 + \ln \epsilon_r} \text{ and } \frac{S}{h} \leq \frac{10}{3(1 + \ln \epsilon_r)} \quad (1)$$

where,  $h$  is the substrate thickness (mm) and  $\epsilon_r$  is the relative dielectric constant. Hence,

$$S = W \times G(\epsilon_r, h, Z_0, W) \quad (2)$$

With

$$G = \left[ \frac{1}{8} \exp\left(\frac{60\pi^2}{Z_0 \epsilon_{eff}^{0.5}}\right) - \frac{1}{2} \right]^{-1} \text{ for } Z_0 \leq \frac{60\sqrt{2}\pi}{(\epsilon_r + 1)^{0.5}} \quad (3)$$

$$G = \frac{1}{4} \exp\left(\frac{Z_0 \epsilon_{eff}^{0.5}}{120}\right) + \exp\left(-\frac{Z_0 \epsilon_{eff}^{0.5}}{120}\right) \text{ for } Z_0 > \frac{60\sqrt{2}\pi}{(\epsilon_r + 1)^{0.5}} \quad (4)$$

Where

$$\epsilon_{eff} = \epsilon_{eff}(\epsilon_r, h, Z_0, W) = T_1 \times \left( 1 + \frac{\epsilon_r - 1}{Z_0(\epsilon_r + 1)^{0.5}} T_2 \right) \quad (5)$$

With

$$T_1 = 1 + \tanh \left\{ \frac{Z_0^2 \varepsilon_r^7}{720 \pi^3 (\varepsilon_r + 1)^8} \times \exp \left[ \left( 1 + 0.0004 \varepsilon_r Z_0 \frac{W}{h} \right) \ln \left( \frac{W}{h} \right) \right] \right\} \quad (6)$$

And

$$T_2 = 84.85 \ln \left( 2 \frac{1+g}{1-g} \right) \text{ for } 0.841 \leq g \leq 1, \quad (7)$$

$$T_2 = \frac{837.5}{\ln \left( \frac{2^{1+(1-g^4)^{0.25}}}{1-(1-g^4)^{0.25}} \right)} \text{ for } 0 < g \leq 0.841, \quad (8)$$

$$g = \left\{ \frac{\exp \left( \frac{\pi(1+Q)W}{2h} \right) - \exp \left( \frac{\pi W}{2h} \right)}{\exp \left( \frac{\pi(2+Q)W}{2h} \right) - 1} \right\}^{0.5} \quad (9)$$

$$Q = G |_{\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}} \quad (10)$$

where  $\varepsilon_{eff}$  = effective relative dielectric constant,  $Z_0$  = line characteristic impedance (ohm). The CPS arm length can be obtained by using the equation (11).

$$L_{cps} = \frac{c}{2f \sqrt{\varepsilon_{eff}}} \quad (11)$$

## 2.2. Transmission Line Dimension

A microstrip-type transmission line consists of 2 conductors which are a plate with width  $W$ , and ground plane. Both of them are separated by substrate which has  $\varepsilon_r$  with thickness  $h$ . Because  $Z_0$  is given, width of the microstrip line can be derived by the equation below.

$$\frac{W}{h} = \frac{8e^A}{e^{2A}-2} \text{ for } \frac{W}{h} < 2 \quad (12)$$

$$\frac{W}{h} = \frac{2h}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right\} \text{ for } \frac{W}{h} > 2 \quad (13)$$

$$A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right)} \quad (14)$$

$$B = \frac{377\pi}{2Z_0 \sqrt{\varepsilon_r}} \quad (15)$$

The effective relative dielectric constant of microstrip lines can be determined by the equation below [2].

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12h/W}} \quad (16)$$

## 2.3. Array Structure

Array structure is a structure that allows several components to be used simultaneously. In this design, T-Junction is used as divider circuit producing a parallel impedance distribution. Inputs are distributed with a pair of output lines so that the input impedance equivalent with the parallel circuit impedance in the output line [7].

### 2.4. Matching Impedance Technique

Matching impedance technique is used to adjust the different impedances which are line characteristic impedance ( $Z_0$ ) and load impedance ( $Z_L$ ). In this design, transformer  $\lambda/4$  is used as impedance matching technique in the transmission line. The length of transformer  $\lambda/4$  line is gained by this equation [4,6].

$$l_f = \frac{\lambda_g}{4} \quad (17)$$

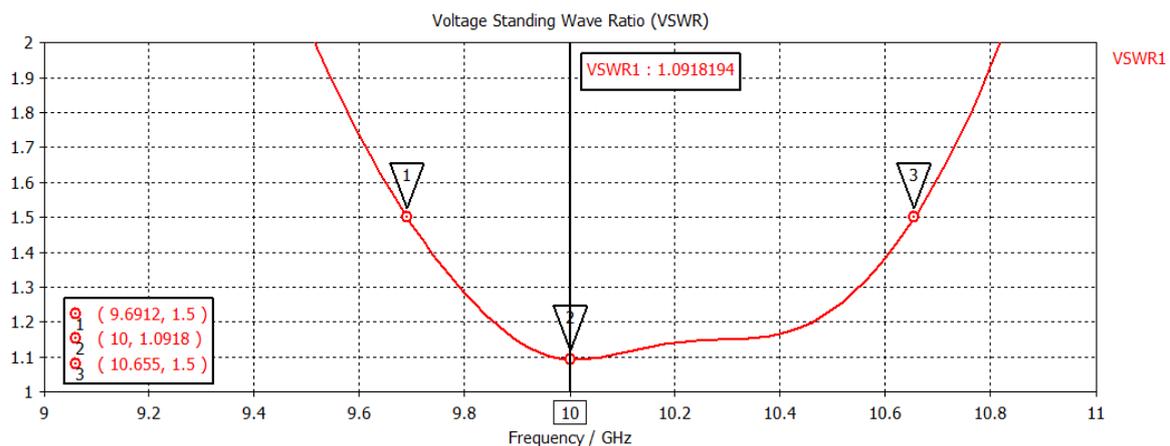
$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{reff}}} = \frac{c}{f\sqrt{\epsilon_{reff}}} \quad (18)$$

## 3. Designing and Simulation

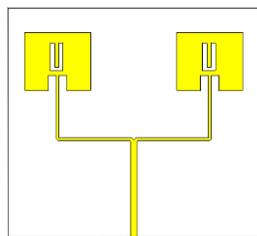
In this section, we will show the design, simulation, realization and measurement results, from prototypes of the antenna and optical modulator that the authors created.

### 3.1. Simulation of Antenna Patch U-Slot

In a microstrip slot the inductive coupling antenna is induced from the supply line to the slot. The greater coupling effect that occurs will reduce the circuit quality factor. The decreasing quality of the circuit quality factor will increase the bandwidth [9].



**Figure 1.** The VSWR of antenna Inset-Fed Array with U-Slot



**Figure 2.** Design of Inset-Fed Antenna Arrays with U-Slots Antenna



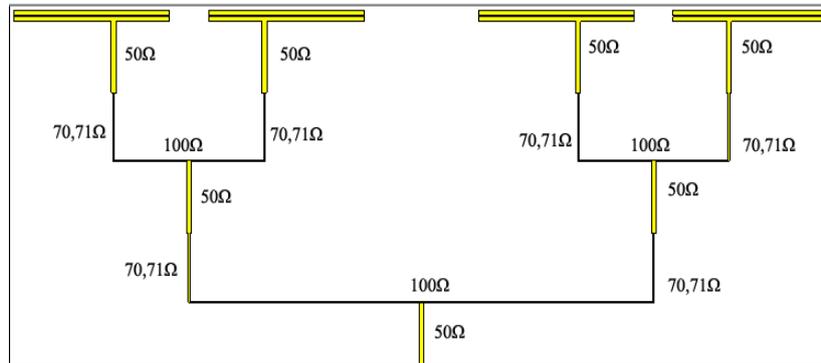
**Figure 3.** Realization of Inset-Fed Arrays with U-Slots

### 3.2. Simulation of Optical Modulator

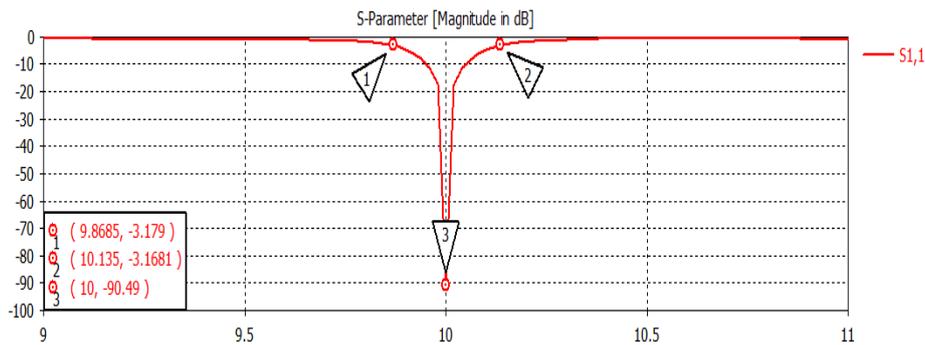
The optical modulator consists of 4 CPS modules which are calculated to generate impedance values is shown in Fig. 4. The substrate used is Lithium Niobate ( $\text{LiNbO}_3$ ) which has a large electro optical coefficient; [6,10,11]. Frequency of radio waves (RF) to be used for 10 GHz which is planned to be fed

through Microstrip Patch-u slot 2 x 1 array antennas. Light wave used for carrier is generated from laser diode with wavelength 1550 nm.

The simulation of optical modulator using electromagnetic simulation software application [4] and the simulation results are shown in Fig. 5. It can be seen that frequency response shown by  $S_{11}$  parameter at 10 GHz optical modulator works well with value of 90 dBm.

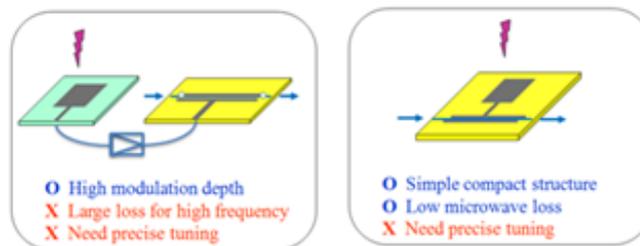


**Figure 4.** Design of Optical Modulator Structure 4x1 Array



**Figure 5.** Graph  $S_{11}$  optimum optical modulator result of 4x1 array

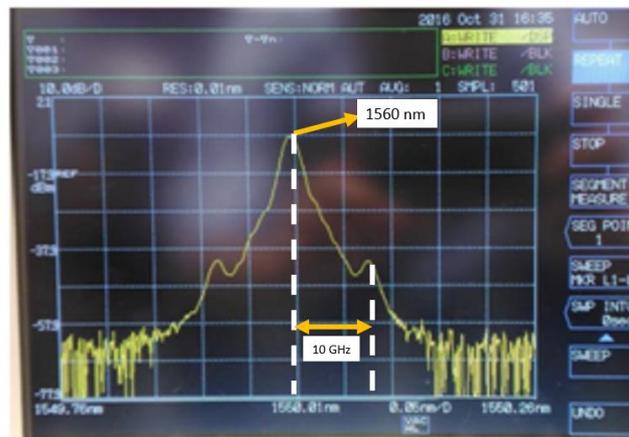
The modulator design is depicted in Fig. 6. On the left hand side, there is a discrete modulator where the microstrip patch and the CPS are separated by a cable. On the right hand side, there is a compact structure of integrated modulator consists of CPS that is united with the patch, without using a cable.



**Figure 6.** Block design of Discrete modulator and Integrated Modulator

#### 4. Measurement and Analysis

The measurement detail of the fabricated antenna as shown in figure 3. is not reported here, but the simulation result can be seen in figure 1. that the antenna is operated for 10GHz microwave bands and has VSWR 1.1. The measurement result of integrated modulator using Vector Network Analyzer (VNA) can be seen in figure 7. Based on this results, the both devices can be used and integrated between the patch antenna and optical modulator for receiving wireless 10GHz microwave bands and converting it to lightwave signals.



**Figure 7.** Frequency Response Measurement Results from Optical Modulator

#### 5. Conclusion

The 10 GHz integrated optical modulator with CPS 2x1 array antenna has been made and evaluated. By analyzing the frequency response, it can be concluded that this system works well according to the simulation. The array structure can reduce the return loss, the more array structure used, the smaller of the return loss generated. With the decrease in return loss, the power received by the device approaches the power provided by the source. The CPS gap is related to capacitance so that the gap change from CPS can emit the change of the working frequency and impedance of the optical modulator. With the change of the impedance, the changes will affect to the return loss. In the future we will report of the antenna measurement detail and combine both with the modulator measurement.

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